Long-Term Follow-Up of Atrial Contraction After the Maze Procedure in Patients With Mitral Valve Disease

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OBJECTIVES
We sought to determine the effectiveness of the maze procedure for maintaining sinus rhythm and atrial contraction for a long period in patients with mitral valve disease.

BACKGROUND
Although the maze procedure for atrial fibrillation (AF) has been effective in restoring sinus rhythm in patients with mitral valve disease, the long-term results of this procedure have not been determined.

METHODS
We echocardiographically studied 94 consecutive patients with mitral valve disease before, as well as early (3.1 ± 3.3 months) and late (2.2 ± 0.9 years) after, the maze procedure. Peak velocity and the time-velocity integral of the left ventricular (LV) diastolic filling wave during atrial contraction (A wave), as well as the atrial filling fraction (calculated as the ratio of the time-velocity integral of the A wave to total diastolic filling), were obtained from transmural flow recordings. Peak A wave velocity ≥10 cm/s was considered to indicate echocardiographic evidence of effective atrial contraction.

RESULTS
Regular rhythm with P waves was restored in 70 patients (74%) in the early stage and in 59 patients (63%, p = 0.09) in the late stage after the maze procedure. Forty-seven patients (50%) in the early stage and 36 patients (38%, p = 0.14) in the late stage showed effective atrial contraction by Doppler echocardiography. Left atrial (LA) and LV end-diastolic diameters significantly decreased after the procedure (from 59 ± 13 to 48 ± 7 mm, p < 0.01; and from 54 ± 9 to 47 ± 5 mm, p < 0.01, respectively) and did not show significant changes during the follow-up period. Once atrial contraction was resumed, its degree did not change between the early and late stages after the maze procedure (17 ± 6% vs. 17 ± 6% for atrial filling fraction).

CONCLUSIONS
Sinus rhythm and atrial contraction recovered early after the maze procedure in most patients and were maintained for more than two years. Once active atrial contraction was resumed, the degree of contraction did not change thereafter. These results demonstrate that the maze procedure is effective for a long period in patients with mitral valve disease.

Atrial fibrillation (AF) is a frequent complication in patients with mitral valve disease, causing systemic embolism, cardiac chamber dilation and decreased cardiac output. Because AF with mitral valve disease is associated with significant morbidity and mortality, electrical or medical cardioversion has been attempted after mitral valve surgery (1–5). There have been several studies on long-term follow-up of cardiac rhythm after electrical cardioversion after mitral valve surgery (2–5), and the maintenance rate of sinus rhythm does not seem satisfactory (2–4).

Cox et al. (6,7) have designed the maze procedure as a surgical treatment for patients with AF in whom conventional medical therapy has failed. Kosakai et al. (8,9) have reported a modified maze procedure and proved its efficacy in patients with chronic AF associated with mitral valve disease. We have also shown the efficacy of the maze procedure in patients with a giant left atrium associated with mitral valve disease (10). Thus, the maze procedure for AF has been effective in restoring sinus rhythm (7,8,11). However, most previous studies have focused mainly on whether the maze procedure could restore regular rhythm after the procedure (7–9,11,12), and only a few studies have mentioned the serial changes of effective atrial contraction (9,13,14). Moreover, to our knowledge, there have been no reports on the long-term follow-up of cardiac rhythm and atrial contraction after the maze procedure in patients with mitral valve disease. In the present study, we determined the effectiveness of the maze procedure for restoring and maintaining sinus rhythm and atrial contraction for a long period in patients with mitral valve disease.

METHODS
Patient group. Between June 1992 and October 1994, 104 consecutive patients with mitral valve disease underwent a modified maze procedure simultaneously with open heart surgery for refractory AF and underlying organic lesions. Of these 104 patients, three who died during the hospital
period and 7 who did not regularly visit the hospital after discharge were excluded. Thus, a total of 94 patients (35 men and 59 women, mean [±SD] age 58 ± 9 years [range 32 to 75]) were enrolled in this study. All patients had mitral valve disease and chronic AF, defined as AF lasting longer than six months (mean duration 8.7 ± 6.7 years [range 0.5 to 30]). Twenty-seven patients had mitral stenosis; 37 had mitral regurgitation; 18 had both mitral stenosis and regurgitation; and 12 had prosthetic mitral valve failure.

The modified maze procedure was simultaneously performed with mitral valve surgery (n = 94), aortic valve surgery (n = 30), tricuspid annuloplasty (n = 34), left atrial (LA) plication (n = 8) and coronary artery bypass graft surgery (n = 1) (Table 1).

**Maze procedure.** We have modified the maze procedure originally designed by Cox et al. (6). Details of our modified procedure have been previously reported elsewhere (8). The major modifications include changes in atriotomy lines, to preserve the sinus node arteries, and use of cryoaablation instead of atriotomy and re-anastomosis, to simplify the procedure. Other modifications are transection of the superior vena cava and detachment of the left ventricle (LV) at the circumferential left atriotomy around the pulmonary veins, to improve exposure, and manipulation of the mitral valve.

**Table 1. Patient Characteristics**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Mean age (years)</td>
<td>58 ± 9</td>
</tr>
<tr>
<td>Men/women</td>
<td>35/59</td>
</tr>
<tr>
<td>Duration of AF (years)</td>
<td>8.7 ± 6.7</td>
</tr>
<tr>
<td>Mitral valve disease</td>
<td></td>
</tr>
<tr>
<td>MS</td>
<td>27 (29%)</td>
</tr>
<tr>
<td>MR</td>
<td>37 (39%)</td>
</tr>
<tr>
<td>MSR</td>
<td>18 (19%)</td>
</tr>
<tr>
<td>PVP</td>
<td>12 (13%)</td>
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<tr>
<td>Additional procedures</td>
<td></td>
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<tr>
<td>MVR</td>
<td>57 (61%)</td>
</tr>
<tr>
<td>MVP</td>
<td>32 (34%)</td>
</tr>
<tr>
<td>OMC</td>
<td>5 (5%)</td>
</tr>
<tr>
<td>AVR</td>
<td>26 (28%)</td>
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<tr>
<td>AVP</td>
<td>4 (4%)</td>
</tr>
<tr>
<td>TAP</td>
<td>34 (36%)</td>
</tr>
<tr>
<td>LAP</td>
<td>8 (9%)</td>
</tr>
<tr>
<td>CABG</td>
<td>1 (1%)</td>
</tr>
</tbody>
</table>

Data are presented as mean value ± SD or number (%) of patients.

**Electrocardiography.** A standard 12-lead electrocardiogram (ECG) was recorded from all patients every two or three days during the hospital period and at their regular monthly visits to the hospital after discharge. The ECGs were analyzed to determine the cardiac rhythm and the presence or absence of electrical atrial activity (P wave).

**Ultrasound examination.** Ultrasound examinations were performed with a commercially available ultrasound system (SSD 870, Aloka, Tokyo, Japan; SSH-160A, Toshiba, Tokyo, Japan; or Sonos 2000, Hewlett-Packard, Andover, Massachusetts) using a 2.5-MHz imaging transducer before (1.6 ± 3.6 months), as well as early (<6 months [mean 3.1 ± 3.3]) and late (>1 year [mean 2.2 ± 0.9]) after, the operation. The LA and LV end-diastolic and end-systolic diameters were determined from the M-mode or B-mode echocardiograms, and LV fractional shortening was measured.

Transmitral flow velocity was measured with pulsed Doppler echocardiography, positioning a sample volume at the level of the mitral tip in the apical four-chamber view, and was recorded on a strip chart at a paper speed of 100 mm/s. Peak velocity and the time-velocity integral of the late filling wave (A wave) were determined. When the deceleration line of the early filling wave did not reach baseline, the time-velocity integral of the A wave was measured as an area above the extrapolation line of early filling wave deceleration. The atrial filling fraction was derived as the ratio of the time-velocity integral of the A wave to total diastolic filling. Each measurement was obtained as an average of six to eight consecutive beats. We arbitrarily considered that a peak A wave velocity ≥10 cm/s indicated echocardiographic evidence of effective atrial contraction (10). The data were analyzed by one investigator (S.Y.) who had no knowledge of the patients’ clinical information.

**Statistical analysis.** All data are expressed as the mean value ± SD. The Fisher exact test was used to assess differences in the incidences of regular rhythm, P waves and A waves between the early and late stages after the operation. Atrial variables between the early and late stages were compared by using the paired t test. Other echocardiographic variables during the study period were assessed by one-way repeated measures analysis of variance, followed by the Scheffé test. We considered the results significant at p < 0.05.

**RESULTS**

**Electrocardiographic findings.** In the early stage, a regular rhythm was noted on the ECG in 75 (80%) of the 94 patients, and 19 (20%) had AF. In the late stage, a regular rhythm was seen in 66 patients (70%), and 28 (30%) had AF. The incidence of patients with a regular rhythm was not statistically different between the early and late stages (p = 0.14).

P waves appeared 0.6 ± 0.9 months after the operation.
Thirty-six patients (51%) had restored P waves within one week after the maze procedure. Not all patients with a regular rhythm had P waves; five patients in the early stage and seven patients in the late stage who had a regular rhythm had no P waves on any ECG lead. Thus, the electrical atrial activity demonstrated by the presence of P waves was resumed in 70 patients (74%) in the early stage and in 59 patients (63%) in the late stage (Fig. 1). The incidence of patients with P waves tended to decrease in the late stage (p = 0.09).

**Ultrasound variables.** Figure 2 shows changes in the echocardiographic variables before and after the operation, with normal ranges shown by the hatched area (15). The LA and LV end-diastolic diameters significantly decreased after the procedure and did not show significant changes during the follow-up period (LA diameter: 59 ± 13 vs. 48 ± 7 vs. 49 ± 8 mm; LV end-diastolic diameter: 54 ± 9 vs. 46 ± 5 vs. 48 ± 6 mm for the operation and in the early and late stages, respectively; p < 0.01). Left ventricular fractional shortening significantly decreased after the procedure (from 35 ± 9% to 30 ± 8%; p < 0.01) and tended to increase in the late stage (32 ± 8%; p < 0.01 vs. before the operation and p = 0.07 vs. early stage).

**Atrial contraction after the maze procedure.** During the follow-up period, 47 patients (50%) in the early stage and 36 patients (38%, p = 0.14) in the late stage showed atrial contraction, as demonstrated by a restored transmitral A wave (≥10 cm/s) (Fig. 1). A waves appeared 2.6 ± 2.6 months after the operation. Of the 47 patients who had resumed atrial contraction in the early stage, 35 (74%) maintained sinus rhythm with atrial contraction, 8 (17%) maintained sinus rhythm but without effective atrial contraction and 4 (9%) reverted to AF in the late stage. Only one patient did not resume atrial contraction until the late stage. Thus, most patients had a restored A wave in the early stage.

Of the 35 patients with effective atrial contraction in both the early and late stages, peak velocity and the time-velocity integral of the A wave and atrial filling fraction remained unchanged (Fig. 3). A wave peak velocities were 44 ± 18 and 43 ± 13 cm/s; time-velocity integrals were 5 ± 2 and 4 ± 2 cm; and atrial filling fractions were 17 ± 6% and 17 ± 5% in the early and late stages, respectively. Although the mean A wave peak velocity and mean time-velocity integral were in the normal range, the atrial filling fraction was still lower than the normal values shown by the hatched area of Figure 3 (16).

Atrial contraction may depend on the surgical results, as well as other factors, such as the presence of prosthetic valve dysfunction, hypertension and left heart failure. In the present study, no patient showed prosthetic valve dysfunction on the echocardiogram. Six patients had hypertension, and one patient had congestive heart failure requiring hospital admission. All of them had restored sinus rhythm, and four of them showed effective atrial contraction in both the early and late stages.

**Complications during the follow-up period.** All of the patients with a mechanical valve had been receiving warfarin for anticoagulation. Transient cerebral ischemic attacks occurred in two patients with a regular rhythm at 12 and 24 months after mechanical mitral valve replacement, respectively. These patients regained a regular rhythm, and one of them had effective atrial contraction with a peak A wave velocity of 29 cm/s at 12 months after the procedure. Their International Normalized Ratios (INR) before the ischemic attacks were 2.22 and 2.71, respectively, and they were discharged without any neurologic signs. Intracranial bleeding occurred in one patient, and retroperitoneal bleeding occurred in the other patient at eight months and nine months after mechanical mitral valve replacement, respectively, but they fully recovered. Seven patients had the complication of sick sinus syndrome, which required pace-
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Restoration and maintenance of atrial contraction after the maze procedure. The maze procedure has been reported as effective in restoring sinus rhythm in patients with AF with and without underlying organic heart disease. However, restoration of both sinus rhythm and atrial contraction is apparently different, and the rate of restoring atrial contraction varies from 21% to 95% (8,10,11,14,17,18). The percentage of patients with restored atrial contraction seems to differ with the etiology of AF. More than 90% of the patients with lone AF or an atrial septal defect had restored atrial contraction (7,19), whereas 21% to 90% of patients with mitral valve disease had restored atrial contraction after the maze procedure (10,12,18). In our study, 50% of the patients resumed atrial contraction in the early stage.

The LA filling fraction in patients who have had the maze procedure has been reported as smaller than that in age-matched control subjects (11,12,14), consistent with our results. Nonphysiologic coupling of atrioventricular contraction caused by delayed LA activation (20), excision of the LA appendage and incision of the LA wall may relate to the decrease in LA contractility. In our preliminary data, the LA filling fraction after the maze procedure did not differ between patients with and those without mitral valve disease (16 ± 5% vs. 17 ± 5%, respectively, at 12 months after the maze procedure). Thus, it is possible that the reduced LA filling fraction after the maze procedure may not be due to the underlying disease, but rather due to the maze procedure itself. Recently, a new surgical procedure for AF (i.e., the radial approach), in which atrial incisions radiate from the sinus node to the atrioventricular annular margins, has been introduced (20). This procedure may provide more physiologic LA function as compared with the maze procedure.

Long-term follow-up of electrical and mechanical atrial activities. It has been reported that LA function is gradually recovered in the first three months, and sinus rhythm is found in 58% to 96% of patients at 12 months after the maze procedure (9,10,14). However, the long-term results of this procedure in patients with mitral valve disease are unknown. Only 20% to 53% of patients can maintain sinus rhythm past one year after simple mitral valve surgery and intraoperative cardioversion (2–4). In the present study, sinus rhythm was noted in 80% of patients in the early stage and was maintained in 70% in the late stage. Effective atrial contraction was recovered in 50% of patients in the early stage and in 38% in the late stage. Thus, both the electrical and mechanical atrial activities after the maze procedure seem to be well preserved for a long period, as compared with those after simple mitral valve surgery.

We have demonstrated that restoration of electrical atrial activity was not comparable to that of mechanical atrial activity at 12 months after the procedure (10). In this study, there was a discordance between the restoration of electrical atrial activity and that of mechanical atrial activity, not only in the early stage, but also in the late stage. It appears that mechanical activity is more refractory than electrical activity after the maze procedure in patients with mitral valve disease, even after more than two years.

Clinical implications. The maze procedure was first introduced by Dr. Cox in 1991. Since then, a number of studies have been performed to clarify the effects and the results of this procedure (7,8,11,12,14,18). However, there have been surprisingly few reports on the long-term results of this procedure (9,13,14). To the best of our knowledge, this is the first report to clarify the long-term results of cardiac rhythm and atrial function after the maze procedure in patients with AF and mitral valve disease. Because many patients with mitral valve disease have concomitant AF, our results should be clinically significant.

Kawaguchi et al. (9) reported changes in cardiac size and contraction after the maze procedure for AF associated with organic heart disease. They showed that LA dimensions significantly decreased and did not change during the follow-up period in patients with AF after the maze procedure, consistent with our results. In contrast, in patients without the maze procedure, the LA dimension decreased early after mitral valve surgery, but returned to the preoperative level subsequently. This suggests the importance of sinus rhythm in preventing re-dilation of the LA dimension. Gosselink et al. (21) reported reduction of atrial size only in patients remaining in sinus rhythm after cardioversion. We suppose that the extensive suturing of the left atrium made during the maze procedure would prevent atrial re-dilation, which may help to maintain normal sinus rhythm. The reduction of the LA dimension after the maze...
procedure may contribute to reducing the risk of thromboembolism.

**Study limitations.** We speculated, on the basis of the transmural A wave findings, that mechanical atrial activity was more refractory than electrical atrial activity after the maze procedure in patients with mitral valve disease. Some patients who had P waves without significant transmural A waves might have had right atrial contraction, as demonstrated by the tricuspid A wave. However, in this retrospective study, we did not measure the tricuspid velocity in most of the patients. We evaluated LA contraction only by transthoracic Doppler echocardiography. Cox (22) demonstrated that some patients who showed no apparent LA contraction by transthoracic echocardiography showed LA contraction by transesophageal echocardiography. Thus, we may underestimate the true occurrence of postoperative atrial contraction.

Factors affecting restoration and maintenance of atrial contraction after the maze procedure include AF duration (23), LA diameter (10), a history of hypertension and the presence of prosthetic valve failure, among others. In the present study, we found that patients with hypertension or those with poor LV function could have restored sinus rhythm and atrial contraction. The effect of each factor should be investigated in another study.

We have not determined whether a successful maze procedure can reduce the risk of thromboembolism. Moreover, we have not determined the clinical significance of restored atrial contraction, which is still lower than that of the normal population. Most of our patients underwent valve replacement with mechanical valves, requiring long-term anticoagulation. Randomized studies should be performed to evaluate the clinical significance of the maze procedure in terms of reducing thromboembolic events.

Because the number of patients in this study was limited, statistical power analysis showed that most variables had sufficient power (99% for the incidences of sinus rhythm, P wave and A wave; 98% for LA diameter; 99% for LV end-diastolic diameter; 98% for LV fractional shortening; 92% for A wave time-velocity integral), but some variables had low power (32% for A wave velocity, 12% for atrial filling fraction), when comparing the early and late stages. Furthermore, if we would detect a 10% difference (alpha = 0.05, beta = 0.2) in the incidences of sinus rhythm or the appearance of P waves and A waves between the early and late stages, the sample size needed would be 125 patients, which is larger than the number of patients in our study. Nevertheless, our results are encouraging and should be substantiated by additional patients.

**Conclusions.** We serially assessed atrial function before and early and late after the maze procedure in patients with mitral valve disease, by using Doppler echocardiography. A regular rhythm with P waves was restored in most patients in the early stage after the maze procedure, which was maintained for more than two years. Fifty percent of patients in the early stage and 38% in the late stage showed effective atrial contraction by echocardiography. Once atrial contraction was resumed, the degree of atrial contraction did not change thereafter. These results demonstrate that the maze procedure is effective for a long period in patients with mitral valve disease.

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**REFERENCES**